DRAFT

Science Benefits of Advanced Geosynchronous Observations

The Scientific Basis for the Joint NASA/NOAA
Advanced Geosynchronous Studies (AGS) Program

September 1998

Executive Summary

This document presents the scientific basis for advanced geosynchronous observation of the Earth's atmosphere and land and ocean surfaces. This document serves as the scientific foundation for the joint NASA/NOAA Advanced Geosynchronous Studies (AGS) program and the document's key points are derived from the Advanced Geosynchronous Studies (AGS) Science Workshop held in College Park, MD March 23-25, 1998.

The overall science goal of AGS is the increased understanding of physical, chemical and dynamical processes in the Earth's atmosphere and at the planet's surface.

The more specific goals are to:

1) Advance our understanding of rapidly evolving phenomena and diurnal processes in the Earth's atmosphere and at the planet's surface.

2) Understand the role of the above processes in global and regional energy, water and constituent cycles and their impact on climate variations.

3) Apply this knowledge to the development of advanced space instruments, missions and techniques for operational monitoring and forecasting of significant and hazardous weather.

High priority science questions are presented in four research areas: Climate Processes, Atmospheric Chemistry, Atmospheric Dynamics, and Surface (Land and Ocean) Processes. These questions lead to a set of geophysical observational guidelines that serve as a first step in determining observational and instrument requirements for research/operational missions to address the science questions.

There is shown to be a close relation of the science questions and the geosynchronous observations to the priorities of NASA Earth Science program and to NOAA's operational goals. The synergism of future geosynchronous observations with those from both research and operational low-Earth orbit (LEO) satellites is also described. The current instruments under study by the AGS program are shown to be critical in addressing the science questions posed.

A current focus of AGS is the development of a joint NASA/NOAA mission concept that would combine observations to answer high priority questions for the research community and meet NOAA's requirement for development of its next generation geosynchronous imager and sounder.

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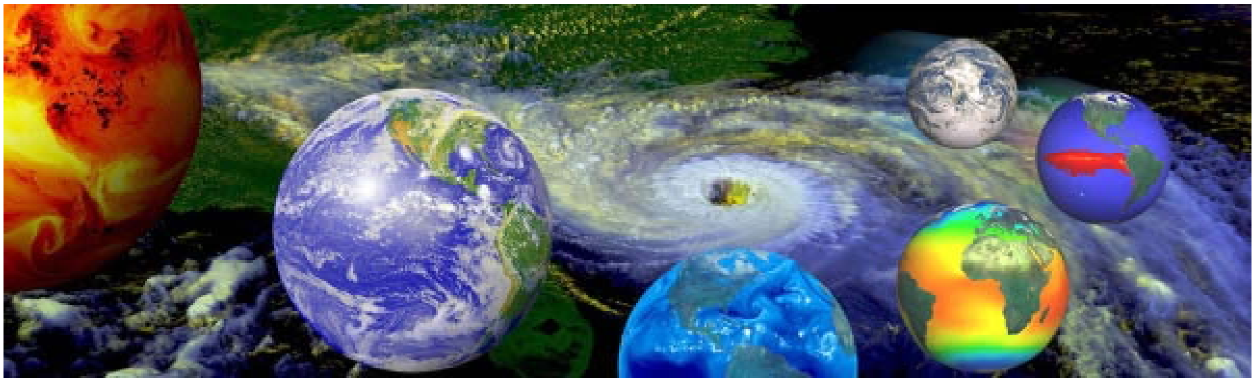

INTRODUCTION

This document describes the benefits that would result from advanced geosynchronous satellite observations, both for Earth science research and for the operational analysis of weather and climate.

The Earth has many fast and slow modes. The fast modes are called "weather" (e.g. temperature, humidity, clouds, precipitation, and radiation), especially on the local scale. The slow modes (e.g. soil, vegetation, rivers, lakes, oceans, ice, and greenhouse gasses) are called "climate", especially on the global scale. All these weather and climate modes, scales, and processes interact significantly.

If we hope to make reliable predictions of weather and climate, we have to monitor land, sea, and air on their natural scales. The main energy pumps are the annual and diurnal cycles, each with comparable driving power. The Earth's response to the cyclical solar drivers is episodic and irregular. Therefore, we must resolve not only the seasonal cycle for many years, but also variations in the diurnal response cycle, and the powerful but irregular exchanges (storms) over the globe.

Unfortunately for analysts, changes by only a few percent in some rapidly varying components are significant for weather and climate (e.g. atmospheric temperature, cloudiness, and ozone). Consequently, continual large-scale coverage with careful calibration and cross-correlation among all instruments is vital for determining variability and trends.

Scale interactions often involve chaotic processes that are not easily simulated by global numerical models. Therefore, a vigorous world-wide campaign of large-scale, uniform observations of land-sea-air behavior has been undertaken by the USGCRP, with the goal of creating a long-term database while the Earth system varies during the next few decades. The slower, large-scale processes will be observed by in-situ instruments and polar-orbiting remote sensing satellites. However, the more rapid hourly variations in critical components (clouds, winds, aerosols, water vapor, precipitation, temperature, etc.) are more difficult to sample uniformly over the globe, and have no associated research satellites. In addition, the inter-agency U.S. Weather

Research Program (USWRP) and the recently sanctioned Global Weather Research Program (GWRP) have science goals and observational requirements that demand the fine time resolution available from geosynchronous observations.

Fortunately, NOAA's current GOES operational weather satellites, and to a lesser extent similar satellites from other countries, already measure to a certain degree many of the fast "climate" variables – clouds, winds, temperature, water vapor, precipitation proxies, and surface conditions every 3 hours over the western hemisphere. In order to improve our understanding of climate processes and associated atmospheric and surface phenomena additional geosynchronous observations are required.

As researchers focus on monitoring and forecasting rapidly evolving weather processes, the need for improved geosynchronous observations with improved spectral, temporal and spatial resolution becomes more critical. In addition, to continue NOAA's progress in using satellite observations to improve their forecast services, well-calibrated digital data sets from geosynchronous satellites must be available for assimilation into numerical models and for use in the issuance of warnings and short term forecasts at NWS field offices.

Therefore, to meet the needs of both the atmospheric, ocean, and land research communities and NOAA’s operational GOES program, the Advanced Geosynchronous Studies (AGS) program was initiated in 1997 to develop technologies and system concepts for Earth observation from geosynchronous orbit for the benefit of both the research and operational communities. It is jointly sponsored by the NASA’s Earth Science Program Office and NOAA’s Geostationary Operational Environmental Satellite (GOES) program.

This manuscript: 1) describes the use of geosynchronous observations for research studies, 2) lists overall science goals and science questions that can be addressed from geosynchronous orbit, 3) reviews NASA's Earth science priorities and research objectives and the role of geosynchronous observations, 4) discusses the "value added" to low-orbit observations by corresponding geosynchronous observations, 5) outlines the weather observing needs of the National Weather Service, 6) compares the satellite-observable parameters from EOS and a possible advanced geosynchronous satellite, and 7) describes the newly formed NASA-NOAA group for Advanced Geosynchronous Studies (AGS).

SCIENCE GOALS AND QUESTIONS

The overall science goal of AGS is the increased understanding of physical, chemical and dynamical processes in the Earth's atmosphere and at the planet's surface.

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Many weather and climate questions involve the most highly variable components of the Earth system – clouds, water vapor, aerosols, precipitation, fires, volcanoes, chemical constituents, surface temperature, etc. Observational systems, such as geosynchronous satellites, that fully observe these processes with the fine time resolution required can address many fundamental science questions that are difficult or impossible to answer from observations at a time resolution of once or twice per day.

The following are high priority science questions in four topic areas developed at the recent (March 1998) Science Workshop of the NASA-NOAA Advanced Geosynchronous Studies (AGS) program. These science questions require observations from geosynchronous orbit.

Climate Processes

<u>How can we reduce the uncertainties in radiative forcing of climate by developing a better understanding of the evolution of aerosols and their interactions with atmospheric parameters such as clouds, atmospheric temperature and moisture structure, and surface properties?</u>

- What is the relationship between aerosol sources, transports and sinks?

- What relationship exists between aerosol evolution and atmospheric chemistry?

- What is the rate of smoke production from fires?

- What is the importance of ash production from volcanoes?

<u>What are the relationships between the radiative forcing of climate and the diurnal cycle of cloud evolution and its interactions with atmospheric profiles of temperature and moisture and surface properties?</u>

- What is the relationship between the diurnal cycle of temperature and moisture to the diurnal cycle of radiative forcing?

- How is the uncertainty in diurnal cycle of clouds related to the uncertainty in the mean radiative forcing and its diurnal cycle?

- How do the diurnal cycles of cloud, temperature and moisture change seasonally and interannually?

- How well is the diurnal cycle of radiative forcing, and its seasonal and interannual variability, simulated in climate models?

<u>What is the impact of moisture sources and sinks and their diurnal variability on local, regional and global atmospheric water vapor budgets?</u>

- What is the role of upper-level water vapor in climate processes--are diurnal variations significant?

- What are the most significant processes contributing to the high degree of spatial/temporal variability of water vapor profiles?

<u>What are the key factors related to the spatial, temporal and diurnal variability of local and regional precipitation patterns?</u>

- What is the relationship among the diurnal variation of temperature, moisture, aerosols and surface conditions and the onset and strength of precipitation?

- How is the climatological distribution of lightning related to the intensity and structure of convection?

- What is the fine scale diurnal variation of precipitation and how is it related to the pattern of geography, orography and land use over the continents and the variability of surface temperature over the ocean.

Atmospheric Chemistry

What is the role of convective scale transport in the tropospheric chemistry of ozone, other trace gases, and aerosols?

- What is the role of dry and moist convection in lofting short-lived species from near the surface to the upper troposphere?
- What is the impact of tropopause-penetrating convective systems on stratosphere/troposphere exchange and the budget of ozone and other trace species?
- What is the contribution of lightning to the free tropospheric NOx budget?

How do weather system circulations impact the lifetime, transport and distribution of tropospheric trace gases and aerosols?

- What is the impact of transport from the stratosphere related to strong cyclonic storms on the tropospheric budget of ozone?
- What is the role of fronts, cyclonic storms and mesoscale wave phenomena on the space-time variability of trace gases and aerosols?

What are the characteristics of regional climatologies of trace gases and aerosols and their relation to patterns of emissions and geographic, orographic and meteorological features?

- What are the diurnal variations in trace gases and aerosols and their relation to the diurnal variation of surface and atmospheric phenomena?
- What is the impact of biomass burning, anthropogenic emissions, and wind-blown dust on the local to regional climatology of aerosols and trace gases?

Atmospheric Dynamics

What are the critical dynamical and physical processes governing the initiation and evolution of tropical and mid-latitude convective systems?

- How do convective systems become organized and what factors affect their evolution and demise?

- What are the factors that contribute to the sudden intensification and transition to severe convection in mid-latitude systems?

- What is the relationship between vertical instability and intensity in maritime and continental convection?

<u>What are the key processes related to tropical cyclone intensification?</u>

- What is the relative importance of environmental dynamical influences compared with inner-core dynamics on the intensification and motion of tropical cyclones?

- What is the role of convective outbursts in the inner core region and outer region in rapid intensity change?

- What are the environmental differences between heavy and modest rain-producing storms?

- What are the limitations to predictability of hurricanes and the primary observables and methodologies necessary to achieve these limits?

<u>What is the multiscale dynamical and physical processes governing the genesis, life cycle and structure of extratropical cyclones?</u>

- What are the characteristic mesoscale substructures and their evolution over the life cycle of extratropical cyclones?

- To what extent are mesoscale substructures of extratropical cyclones governed by non-quasigeostrophic dynamics?

- How is the rainfall distribution related to rapid intensification of extratropical cyclones?

Surface (Land and Ocean) Processes

<u>What is the small-scale variability of radiative active constituents in the surface mixed-layer of the coastal ocean, and how is it related to physical and biological processes?</u>

- What is the small-scale variability, both in time and space, of phytoplankton, biomass and productivity, and how is it related to irradiance and mixed-layer depth?

- What is the impact of storms and other short-term events on geological and biological properties in the water column?

- Can natural and anthropogenic hazardous conditions be detected, monitored and predicted?

<u>What are the time-space variability of ocean surface currents and sea surface temperatures (SST) and their interaction with larger-scale processes?</u>

- How are ocean surface currents related to variations in fisheries, pollution, and red tide?

- What are the synoptic characteristics of ocean currents and their relation to weather and climate?

- What is the variability of the diurnal SST cycle and its effect on weather and climate?

<u>What are the significant factors in the variability of land surface fluxes under different geographic, orographic and atmospheric conditions?</u>

- How is the growth-decay cycle of the atmospheric boundary layer related to the evolution of land surface temperature (LST)?

- What are the key factors in accurately determining surface energy and water budgets for different surface conditions through a combination of models and remote sensing observations?

<u>What is the key processes governing surface hydrological processes and their relation to the biosphere?</u>

- How is atmospheric forcing, surface energy and water budgets, soil water storage and runoff generation interrelated on the local, regional and large basin scales?

- What are the characteristics of short-term variation in vegetation and its relation to precipitation and surface characteristics?

The accompanying table shows geophysical observational guidelines related to the four groups of science questions in this section. These guidelines are refinements of conclusions drawn by the working groups at the AGS Science Workshop. They should be considered just as “guidelines”, not explicit requirements for a particular mission or instrument. Needed accuracies or coverage areas are not included in the table. These guidelines, however, are useful in understanding the approximate range of temporal and spatial resolutions that are necessary to make significant research progress in answering the science questions described above. The spatial resolutions vary from 0.5 km (for some cloud and surface information) to 200 km (for wind information for Climate Processes questions). It should be remembered that a guideline of 20 km for a geophysical variable may require much higher resolution radiometric observations. The temporal resolution varies between 15 s (for observation of convective cloud information) to 3 hr for winds and precipitation information for questions related to climate processes.

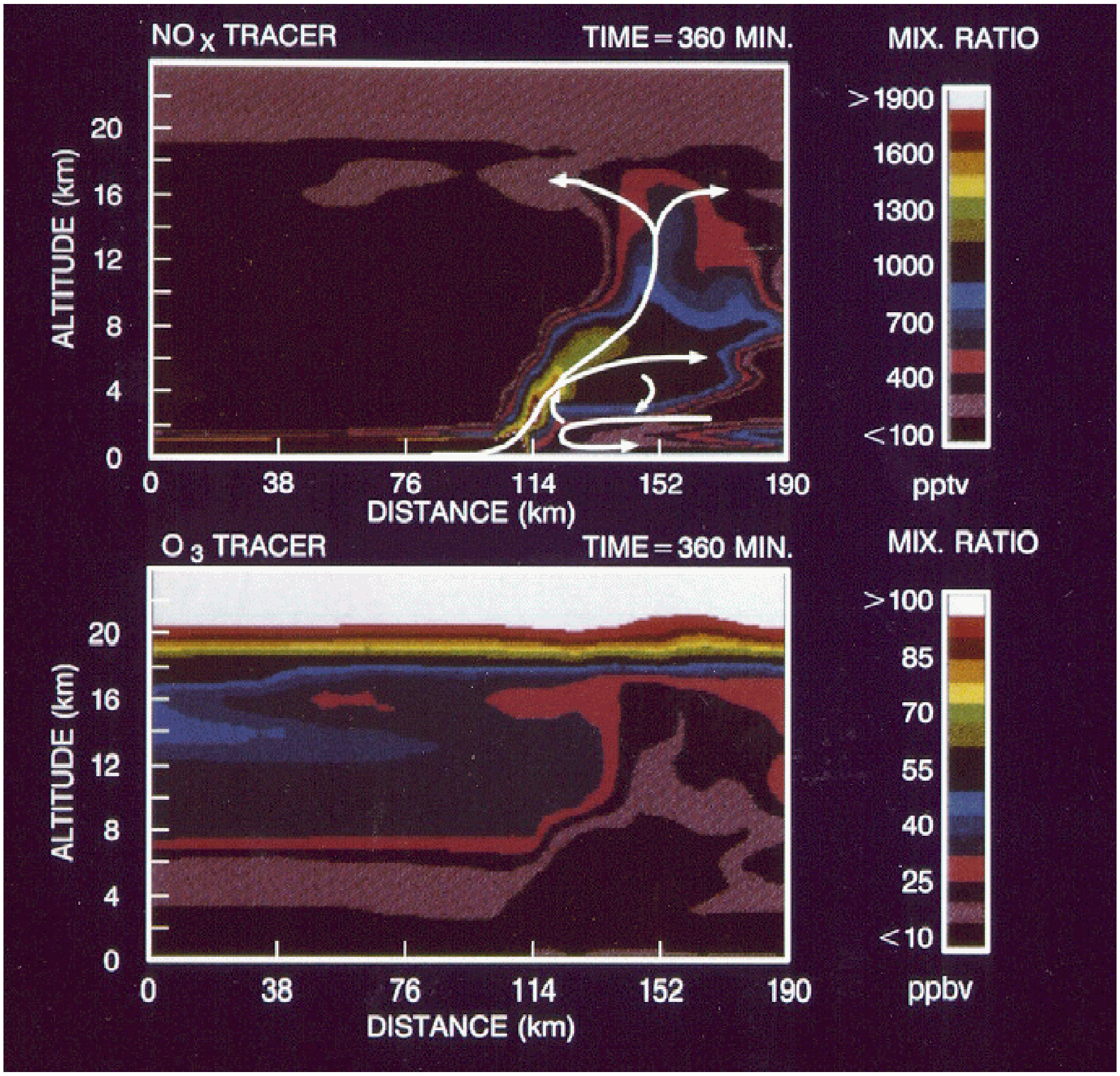

Figure 1 Atmospheric chemistry is intimately related to convective processes with horizontal and vertical scales determined by convection.

Geophysical Observational Guidelines for Research

	Climate Processes				Atmospheric Chemistry				Atmospheric Dynamics				Surface (Land and Ocean) Processes			
	Horz. Res.	Vert. Res.	Time Res.	Notes	Horz. Res.	Vert. Res.	Time Res.	Notes	Horz. Res.	Vert. Res.	Time Res.	Notes	Horz. Res.	Vert. Res.	Time Res.	Notes
Cloud Information	1-4 km	2-3 km	30-60 min.						0.5-5 km	0.5-2 km	15s - 5 min.					
Aerosol Characteristics	1-20 km	0.5-2 km	30-60 min.		4-10 km	1-8 km	30 min. - 2 hr.		1-10 km	.5-2 km	20-40 min.					
Tropospheric Temp.	10-50 km	1-2 km	15-60 min.		10-100 km	1-3 km	30 min. - 2 hr		2-20 km	0.3-1 km	15 min. - 1 hr.					
Tropospheric Moisture	10-50 km	1-2 km	15-60 min.		10-100 km	0.1-8 km	30 min. - 2 hr		2-20 km	1-4 km	15-60 min.					
Winds	100-200 km	2-4 km	1-3 hr.						10-50 km	.5-2 km	15 min. - 2 hr.		10-50 km	.5-2 km	1-3 hr.	
Precipitation	10-30 km	2-8 km	1-3 hr.						1-50 km	2-8 km	10 min. - 1 hr.		4-20 km		30 min. - 1 hr.	
Trace Gases (e.g., O_3, Nox)					4-100 km	1-8 km	30 min. - 2 hr									
Surface Temp.									1-20 km		20-60 min.		1-4 km		30 min. - 1 hr.	SST: 0.5K accuracy
Ocean Currents													20-100 km		6h-1d	
Ocean Biology													0.5-1 km		1-2 hr.	
Surface Characteristics													.5-20 km		1 -6 hr.	
OLR & Net Solar Rad.	10-20 km		30-60 min.													
Lightning	2-5 km		5-15 min.		4-20 km		1-5 min.		4-20 km		20s - 5 min.					

NASA EARTH SCIENCE PRIORITIES AND RESEARCH OBJECTIVES

As NASA's part in the U.S. Global Change Research Program (USGCRP), the Earth Science Enterprise (ESE) has identified scientific priorities and corresponding research objectives that it will pursue in 1996-2002. The following quotations from the NASA-ESE 1996 science research plan is a list of items that can also be observed from geosynchronous orbit:

- "Develop space-based and airborne observations of atmospheric temperature, winds, water vapor and precipitation, aerosol and cloud properties, sea surface temperature, ... "
- "Continue and improve existing time-series of important environmental measurements: ...lower tropospheric water vapor, cloud radiative properties, atmospheric temperature, sea surface temperature,... Implement missing or inadequately sampled observations: water vapor in the upper troposphere and lower stratosphere, tropospheric aerosols, land surface temperature, evaporation,... Develop new technologies for missing observations: precipitation, 3-dimensional winds, cloud microphysical properties, soil moisture and evaporation,..."
- "Apply and develop space technology that can be used in characterizing hazards and reducing disasters... Understand Earth processes which lead to natural disasters."
- "Characterize the global distribution of ozone, chemically active trace constituents, aerosols, and related meteorological parameters, including a long-term subset of these parameters."

Figure 2 Fire zones dominate the low-latitudes, particularly surrounding the tropic rain forests of the equatorial monsoon regions, such as Amazonia. The hot spots are a time-composite from DMSP observations.

The NASA-ESE research areas all have questions about variability and trends in land-water-air constituents. There are several technical solutions for obtaining each answer. Consequently, NASA's Earth Observing System (EOS) satellites in the 1998-2002 era will carry specialized instruments designed to collect information about the variable constituents and interactive processes that shape the planet. Some of these constituents and processes change so rapidly that the research objectives require hourly time resolution.

For the post-2002 era, NASA's ESE has recently made a request for information that continues these themes:

- "Can NASA assist in the development, implementation, testing and evaluation of new applications-oriented sensors that will help the public, other Agencies, State projects, or commercial interests to use the perspective and quantitative measurement capability of space-based observations for the public good?"
- "Climate is the integrated result of weather… We strive to acquire as complete a description of the atmosphere-ocean-land system as possible… We depend heavily for this purpose on systematic observation and analysis carried out by operational environmental agencies for weather and climate forecasting purposes. Accordingly, the Office of Earth Science attributes high scientific value to the improvement of global operational environmental observing and data analysis systems…"
- "Will the frequency and intensity of El Niño phenomena and of severe weather events change in response to environmental changes, and can we achieve a better capability to predict them?"
- "Can we link changes in water vapor, cloud properties and the hydrological cycle to changes in the circulation of the global atmosphere?"
- "Will an increase in atmospheric aerosols offset the heating caused by greenhouse gasses?"
- "How can space observations contribute to better detection and characterization of regional to super-regional air pollution…?"
- "Can space techniques be developed and used which will contribute significantly to improved disaster mitigation for earthquakes, floods, volcanic eruptions, landslides and wildfires?"

The following section discusses how climate information from the low-altitude EOS platforms relates to corresponding weather observations from geosynchronous orbit.

CLIMATE OBSERVING BENEFITS IN THE EOS ERA

EOS will collect a 15 year record of measurements of parameters of the earth system – aerosol concentration, cloud fraction, cloud microphysics, water vapor distribution, temperature distribution, fire occurrence, vegetation cover and primary productivity over the land, ocean productivity, etc. It will collect the information two times a day for the AM platform (e.g. 10:30 a.m. and 10:30 p.m.) and four times a day for measurements that will be repeated in the PM Platform at 1:30 p.m. and 1:30 a.m.). For some earth parameters that have a rate of change of a day or slower, e.g. vegetation, this measurement strategy is satisfactory. But for other measurements, e.g. clouds, water vapor, fires, convective systems and cyclonic storms with rate of change of minutes to hours, there is a strong short-term variability that needs to be measured in order to understand the role of these parameters in climate change. We anticipate the strong variability to be somewhat more important over the land and coastal regions than over the ocean where the diurnal cycle of the solar heating is largely compensated by the large ocean heat capacity. Geostationary satellites are required to measure these highly variable Earth system parameters, and also to establish their diurnal cycle and the seasonal and interannual variability of their daily cycle. A synergism between geosynchronous and polar satellites will provide the full spatial and temporal coverage required to measure changes in the earth system and its climate, where the geosynchronous satellites will concentrate on the most transient earth system parameters, discussed in the following subsections.

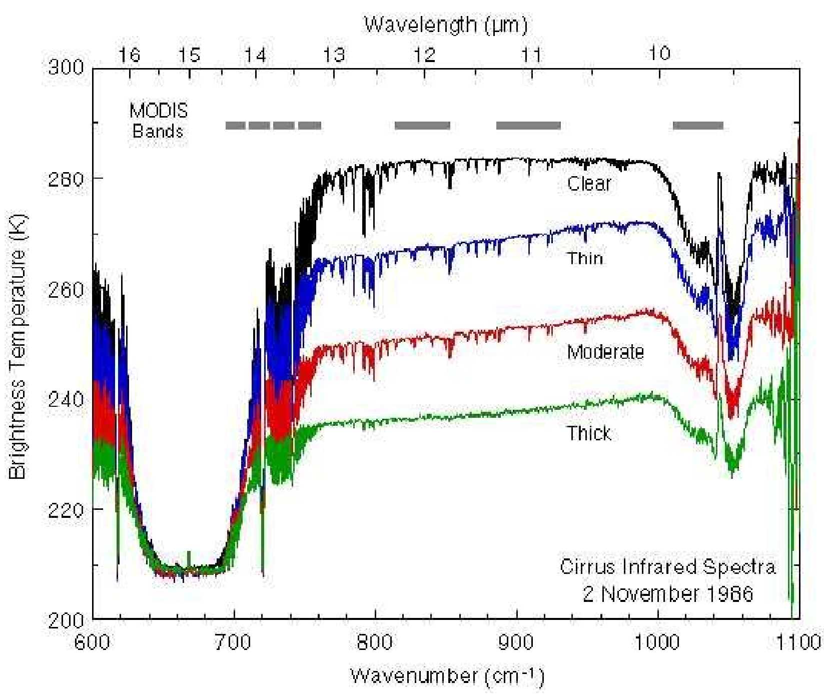

Figure 3 The entire thermal infrared spectrum can be used to retrieve cloud information, the atmospheric temperature and moisture profiles, and even the chemical composition. (Smith, et al., 1988).

Clouds

Clouds are one of the most uncertain feedback mechanisms in the climate change process. While only recently discovered to have a net cooling effect, their impact on climate is quite variable since the balance between the cooling effect by reflecting sunlight to space and the warming greenhouse effect depends on the cloud height and thickness. Climate change (global or regional) may result in changes in the cloud system that may serve as a strong feedback mechanism, positive for an increase in the high cloud fraction or negative for low cloud fraction. This may enhance or decrease, respectively, climate change from greenhouse gases. For example, an increase in the fraction of low-level stratiform clouds by 1%, during the last century may already explain the difference between the measured warming of ~0.5K and the predicted warming of ~1K. If the EOS 15 year record detects a correlation between the warming trend and an increase in the low cloud fraction, a question may still remain whether the increase is a real increase in the total cloud fraction, and therefore an increase in the reflection of sunlight back to space, or just a shift in the diurnal cycle of the cloud fraction that at 10:30 am results in an apparent increase in the cloud fraction for the entire day. Large-scale measurements of the diurnal cycle of these clouds and of a change in the diurnal cycle may resolve this issue. Although this can, in part, be accomplished with processing orbits such as that used with TRMM, the geosynchronous viewpoint will give much higher spatial and temporal resolvability of the diurnal signal due to the much higher time resolution. For example, from geosynchronous orbit, the diurnal signal for even a single day can be resolved, while the TRMM-like orbit requires sampling over a long period and/or over a large domain.

Cloud microphysics affects the interaction of clouds with sunlight and controls the rate of precipitation and, therefore, the cloud lifetime. Cloud microphysics are affected by the concentration and properties of aerosol particles that originate from human and natural sources and also by atmospheric dynamics. EOS will measure the cloud phase and the cloud drop size. Resolving the diurnal cycle of these cloud properties is required to for understanding the impact of aerosol on climate through cloud modification (considered today one of the main uncertainties in climate forcing -IPCC, 1996). Again, we need to know if the interannual change in the cloud properties is due to a real change and not a shift in the diurnal cycle. Since most anthropogenic aerosol is produced over land, the interaction of aerosol with clouds over land is important and is expected to have a strong diurnal cycle.

Water Vapor

Without changes in the concentration and vertical distribution of water vapor the greenhouse effect on the temperature record would be ~4 times smaller. Therefore, the precise response of concentration and distribution of water vapor in the atmosphere to climate change is a decisive feedback mechanism that may determine the importance, or lack thereof, of greenhouse warming. There is evidence that the parameterization of water vapor in climate models is too simple, so detailed measurements are very important. EOS plans to have measurements of total precipitable water vapor and separation into two levels in the AM platform and the best possible vertical structure that can be derived from passive remote sensing in the PM platform. However, the diurnal cycle is still missing. The diurnal cycle of water vapor is very important over land, but may not be very important over the oceans.

Cloud Formation

EOS is planning simultaneous measurements of water vapor distribution, atmospheric temperature profile and aerosol, precursors to cloud formation and the resulting properties of clouds: droplet size and phase, height, cloud top temperature, and reflectance of sunlight. The measurements on the PM platform are more extensive than on the AM platform. It will measure all of the above cloud properties. Measurements of the variability of these properties during the day will be very important, especially for rapidly changing moisture and aerosols. For example, the 6 to 8 micron spectrum can be used to monitor the vertical distribution and motion of water vapor throughout the day.

Figure 4 Water vapor returns to earth as precipitation of both hydrometeors and cirrus cloud particles. Cirrus plays an important role in controlling insolation in regions far from the original place of convection.

Aerosols

Aerosol particles scatter and absorb solar radiation. They also serve as the condensation nuclei and ice particles of clouds. Therefore, modification of the aerosol properties will cause modification of the cloud properties. Both the direct interaction of aerosol with solar radiation and the indirect interaction by modification of cloud properties generates a radiative forcing of climate. Aerosol effects are the largest uncertainty in the radiative forcing of climate, according to the IPCC reports (1992, 1994, 1996). Even though the aerosol forcing is probably half of that of the greenhouse gases, the absolute uncertainty in this forcing is about 4 times larger than the uncertainty in the greenhouse gases.

The aerosol life time is very short (a few days) and their generation very dynamic, varying from hour to hour. Biomass burning aerosol is generated from fires, 80% of them in the tropics, with a very specific diurnal cycle (e.g. 12 pm to 5 pm) that varies from one region and ecosystem to another. Sulfate aerosol are produced from oxidation of sulfur dioxide emitted by industry and cars, oxidation that requires sun light, and therefore have a diurnal cycle. Dust is generated in desert and desert transition zones. It is affected by human induced overgrazing and is a function of the wind distribution, temperature profiles, and sunlight, and therefore should have a strong diurnal cycle. EOS will measure global aerosol mainly during the daylight hours, at 10:30 am for the AM platform and 1:30 pm for the PM platform. Measurements from the TOMS instrument taken once per day will enhance the aerosol measurements over the land and may help to separate between aerosol scattering and absorption over land and ocean. Supplementing this information with the full diurnal cycle from geostationary orbit is of great importance.

Fires

Figure 5 Smoke and fires can be readily detected using red-green-blue visible and near infrared spectral channels. (Kaufman, et al., 1994)

Fires are an indication of deforestation and of land use practices that affect both the land productivity and the atmospheric composition. Most fires are man-made and occur in the tropics, are rather small, and have a duration of up to a few hours. Fires of woody material (e.g. in deforestation) are of a longer duration and fires of grasslands and agricultural waste are of a shorter duration. Wild fires in the mid latitudes and northern regions (e.g. USA and Canada) are of major ecological importance. They are an essential part of these ecosystems, but are also a threat to populated regions directly as fire hazard or indirectly through the emission of polluting smoke. USA Forest Service has a complex policy regarding which fires to fight and which to let burn. This policy was very variable in the last century, resulting in even larger fires (e.g. Yellowstone fire). Presently the Forest Service fire treatment is based only on ground based and aircraft observations.

The EOS MODIS instrument will have special fire channels that with a 1 km resolution will detect fires, establish the rate of combustion of biomass in these fires and may be able to distinguish between new flaming fires and old smoldering fires. However, fire observations by MODIS will be provided no more than 4 times a day (after the launch of PM). Supplementing this information with the geosynchronous diurnal cycle, even if with a lower spatial resolution, is very important and was proven critical in field experiments that concentrated on the biomass burning issue such as SCAR (Smoke, Clouds and Radiation conducted in the US and Brazil).

In this respect, geosynchronous observations can supplement the EOS information by detecting and monitoring the diurnal cycle of the more energetic fires between the EOS observation times. This will be very useful for establishing the role of biomass burning in climate change and land use change and for helping to develop a new, more sophisticated policy for the Forest Service in its decision making and fire fighting. Geosynchronous observations can routinely provide information every 15 minutes on the location and strength of larger wild fires in the western hemisphere.

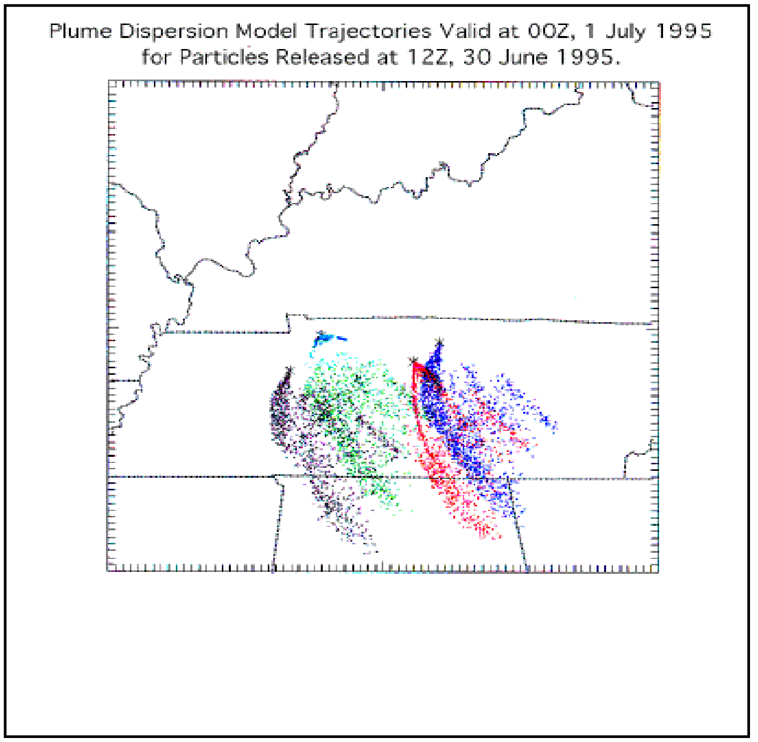

Figure 6 Plume dispersion modeling depends upon accurate knowledge to low level winds.

Trace Gases

There are several trace gases important for the greenhouse effect, for atmospheric chemistry, and for human health and safety: O3, CO, CH4, N2O, CO2, and SO2. EOS instruments will measure these during the overpasses of the AM and PM platforms. However, local weather is a significant factor controlling sources, sinks, diffusion, transport, and deposition patterns of trace gasses in the troposphere. Several of these gases have regional, diurnal, and sporadic behavior that require more frequent and continuous observation due to biological, photochemical, and even volcanic factors. For example, from geosynchronous orbit, one could observe the diurnal cycle of atmospheric ozone, including its spatial variability, horizontal transport, and vertical exchange associated with weather and climate processes.

Atmospheric Temperature and Humidity

The thermodynamic variables in the atmosphere change markedly during the day. Water vapor is particularly variable in the lower troposphere on time scales of hours. Water vapor is important not only to weather, but to radiative, photochemical, aerosol and land processes. The intervals between EOS atmospheric soundings could be supplemented with hourly high resolution soundings of temperature, moisture, cloud and moisture motion ("wind") observations for input into data assimilation and numerical prediction models on global and regional scales in order to evaluate diurnal to interannual impacts. The societal benefits of high resolution temperature and humidity sounds are addressed at length in several following sections of this report.

Natural Hazards

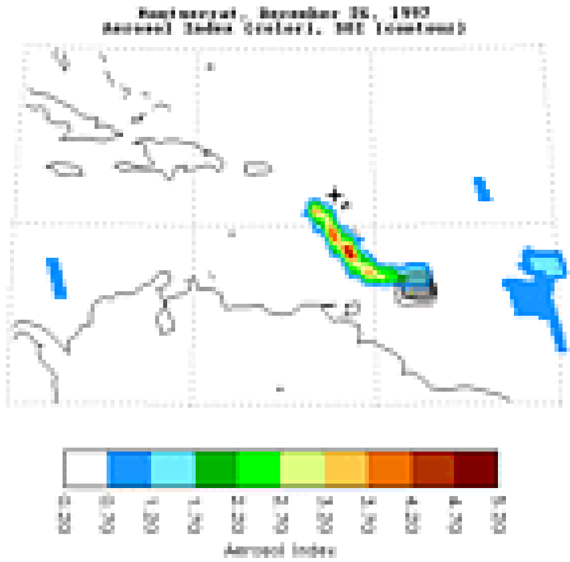

Figure 7 Volcanic eruptions presents a significant hazard to aviation. A variety of remote sensing techniques are available to detect downwind ash and sulfur dioxide, both day and night. (Krueger, et al.,1997)

Sporadic natural hazards like wildfires, lightning storms, and volcanic eruptions are far more easily captured from geosynchronous orbit than from polar-orbiting satellites. Volcanoes in the western Americas and Caribbean basin are readily observed from geosynchronous orbit. Volcanic smoke and ash can be readily detected and traced. With advanced instrumentation, volcanic gases can be identified and measured as they emerge and dissipate. Rapidly varying and deadly flash floods, severe thunderstorms, hurricanes and snowstorms are also best observed and monitored from geosynchronous orbit.

Lightning

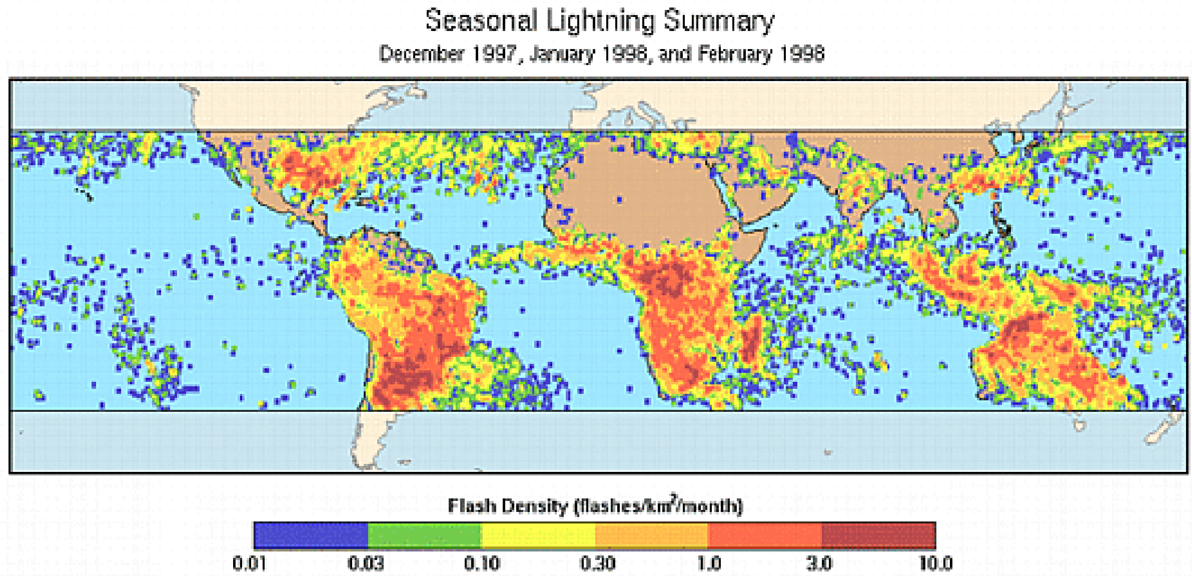

Figure 8 Lightning occurs predominantly within severe convective storms over land areas, where it is an indicator of vigorous vertical motion. Lightning is an indicator of precipitation and convective mixing. It plays an active role in the production of nitrous oxides. (Christian, et al., 1998)

In-flight experience with lightning mapper data demonstrates that it is a useful proxy for intense convection related to ice flux, updraft strength, convective rainfall, diabatic and latent heating, and upper tropospheric water vapor. A lightning mapper is flying on the TRMM satellite. A geosynchronous LM is capable of filling in the enormous fraction of lightning not observed by TRMM over the great thunderstorm belts of the western hemisphere – the southeastern United States, the Gulf of Mexico, the Inter-Tropical Convergence Zone (ITCZ), and the Amazon basin. Continuous observations from geosynchronous viewpoint provides a database to investigate seasonal, annual and interannual variability for studying short term climate change. With uniform day-and-night detection efficiency greater than 90% over large areas, a very complete lightning climatology of the western hemisphere will certainly be generated. Finally, for atmospheric chemistry, lightning plays a significant role in generating nitrous oxides. The natural nitrous oxide budget is a matter of great uncertainty at this time, and long-term observations of one of its sources will prove valuable as the subject develops.

Precipitation

Accurate estimation of precipitation is critical to many of the goals of global change and climate research and also to the goals of understanding atmospheric processes and weather-related natural hazards. Precipitation estimates are available based on passive microwave observations from polar-orbiting satellites such as the SSM/I instrument on the DMSP satellites and the soon-to-be-launched AMSU instrument on NOAA's polar orbiter. The Advanced Microwave Scanning Radiometer (AMSR), which will fly on EOS-PM and on ADEOS II, will improve precipitation estimates from polar orbit through increased resolution and additional, low-frequency channels. The Tropical Rainfall Measuring Mission (TRMM) provides the best rainfall estimations through high-resolution passive microwave observations combined with the first precipitation radar in space. TRMM's low-inclined, processing orbit allows the measurement of the diurnal cycle on a climatic scale.

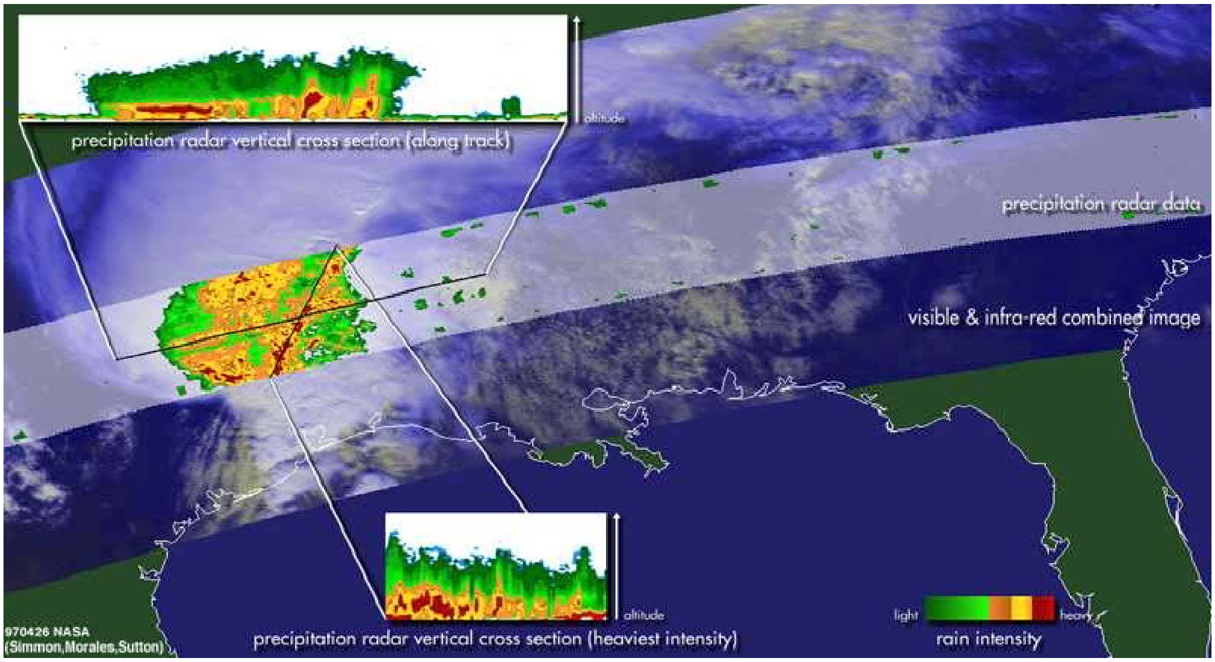

Figure 9 The TRMM satellite's radar provides three-dimensional information about the structure of precipitation within a storm, while corresponding passive imagery of the cloud tops is a surrogate for precipitation estimates. (Kummerow, et al.,1998) The synergy between sparse LEO data and dense GEO data promises to fill the gaps in space-time coverage of precipitation, especially for the diurnal cycle.

However, precipitation is a quantity that varies extremely rapidly in both time and space. Therefore, there has been tremendous effort to estimate precipitation from proxy parameters available from geosynchronous observations. These parameters have typically been cloud characteristics obtained from visible and infrared observations, often combined with conventional information, for example sparse surface raingage data. Improvement of geosynchronous observation of precipitation, perhaps by use of remote observations physically more closely related to precipitation, or by better proxy parameters, would in turn improve precipitation analysis for a number of research areas. These key areas include the analysis of regional climate precipitation patterns, definition of the diurnal cycle of precipitation and the variation of the phase and amplitude of that cycle, and the interaction of precipitation and its associated latent heating with the dynamics of atmospheric systems.

WEATHER OBSERVING BENEFITS IN THE NEXT DECADE

In a time of diminishing resources and performance-based decisions, the NWS has set five science priorities that are directly linked to forecast issues in which relatively little progress has been made over the last 40 years, even with the incorporation of the model-based end-to-end forecast process (Uccellini, 1996). The top five NWS science priorities to support advanced short-term forecasting and warnings through the year 2005 include the study of the processes involved with:

- **Quantitative precipitation forecasting**
- **The effect of topography on local weather regimes including unique weather patterns associated with the Great Lakes and coastal areas**
- **Developing a better understanding of the evolution, intensity changes and movement of tropical cyclones**
- **Conditions conducive for the development of wildfires**
- **Explosive cyclogenesis, especially in the marine environment**

The potential role that geostationary satellite data could play in leading to significant progress in these research areas is discussed below. Also included are a series of critical questions related to each priority item, which must be answered before a clear definition of future operational geostationary requirements can be finalized.

Quantitative Precipitation Forecasting

Quantitative precipitation estimation derived from rain gages and multiple remote sensors is a critical first step to quantitative precipitation forecasting. A critical question emerges:

Figure 10 Rainfall occurs unpredictably on a wide range of space-time scales. Constant observation is required to measure its occurrence and intensity.

- What blend of radar and satellite data from geostationary and polar platforms are required to determine the distribution of precipitation from the global to the mesoscale?

Radar and satellite both offer unique strengths for precipitation estimation but also have limitations. Radar data provides direct detection of precipitation but suffers from range limitations and non-uniform coverage. Satellite data (with the exception of microwave data), can only indirectly detect precipitation, but offers more uniform global coverage than radar. Likewise, the unique strengths of polar and geostationary satellite data can be used to complement each other and compensate for the other's weaknesses.

Satellite data is also an important factor in improving the prediction of precipitation from numerical models, leading to the question:

- What blend of passive IR sounder and microwave sounder data from geostationary and polar orbiters is required for assimilation into numerical models to provide significant improvements to quantitative precipitation forecasting?

Passive IR sounders provide superior horizontal and vertical resolution but are limited to clear areas. Microwave sounders can provide information on temperature, liquid water and water vapor in cloudy areas but cannot match the resolution of the passive IR sounders.

Convective precipitation varies rapidly in time and space.

- What is the optimum temporal frequency of the data required from geostationary sounders to provide input into mesoscale models that would lead to improved forecasts of the mesoscale precipitation patterns?

Satellite sounders are effective tools for determining total precipitable water in a vertical column, which is critical information for QPF. However, determining the vertical distribution of water vapor, especially in the low levels of the atmosphere, would provide additional value in the QPF process, leading to the question:

- What vertical resolution of the geostationary satellite data is required to significantly improve model-based quantitative precipitation forecasts?

Commercial ground-based lightning detection processing systems are designed to display only cloud-to ground strokes and not the much more plentiful cloud-to-cloud flashes. Research has shown that an increase in lighting frequency typically precedes an increase in rainfall rate, which leads to the question:

- Would a lightning mapper from geostationary orbit provide valuable complementary information on precipitation rates that can be used to initialize mesoscale models?

The Effect of Topography on Local Weather Regimes

Results from the NWS Lake Effect Snow (LES) Study indicate that 4 km IR resolution is insufficient to detect individual wind-parallel LES bands.

- What resolution from the imager is required to improve detection of LES bands and thereby improve short-range forecasts?

Preliminary results from studies of LES events indicate that in some cases changes in cloud top glaciation correspond to changes in snowfall rate. Therefore, a more accurate measure of cloud-top glaciation should lead to improved estimates of snowfall rates from LES bands.

- What additional imager channels are needed to improve our ability to determine the degree of cloud top glaciation?

During the NWS LES study, passive IR sounders from GOES-8/9 were of only limited value. There were two basic problems: 1) coarse vertical resolution for defining the vertical distribution of water vapor and the low level stability, and 2) the absence of soundings in cloudy regions.

- What vertical resolution is required from a satellite sounder to provide improved mesoscale model performance during LES situations?
- With the coarse vertical resolution offered by microwave sounders, can they provide any useful cloud information to mesoscale models of LES?

The use of the low-cloud product, produced by differencing GOES IR channel 2 (3.9 microns) from channel 4 (10.7 microns) has resulted in a quantum leap forward in forecasters' ability to detect low clouds and fog at night. However, with the 4 km resolution of the GOES IR imager data, narrow bands of valley fog still escape detection.

- What resolution is required from an IR imager to adequately define the distribution of narrow bands of valley fog for aviation applications?

Figure 11 Geosynchronous orbit is the ideal location for monitoring the development of tropical cyclones in the data-sparse warm oceans.

The Evolution and Movement of Tropical Cyclones

The use of high-density satellite-derived winds has demonstrated potential for improving forecasts of hurricane tracks. In experiments with the Hurricane Research Division's barotropic forecast model (VICBAR), the satellite wind sets yielded modest improvements over control runs in nearly two-thirds of the 72-hour forecasts.

- What additional imager channels are required (i.e. water vapor absorption bands and carbon dioxide bands) to define better the height of wind vectors and provide for improved model performance?

For a select number of cases, the use of satellite derived cloud track winds and water vapor winds has had a positive impact on the analyses of the wind fields surrounding hurricanes and subsequent improvement in numerical prediction.

- What is the optimum temporal and spatial resolution in the visible and IR imager channels for producing cloud track winds in the vicinity of tropical cyclones that will sustain or improve this positive impact over a large number of cases?

Satellite moisture and temperature soundings are critical for defining the near storm environment. Presently, the operational areal coverage of the GOES sounders are limited, such that if conflicting requirements for the ASOS cloud product are met, the areal coverage over the ocean is restricted. A faster sounder would lead to improved forecasts.

- What temporal sounder frequency is required to improve hurricane model performance?

A microwave sounder in geostationary orbit would lead to improved tropical cyclone forecasts by providing soundings in cloud covered areas within the storm. Significant additional meteorological information regarding the strength of a hurricane lies in the magnitude of its warm core temperature anomaly and in the extent of its rain bands, both of which can be detected in microwave data (Staelin, 1997).

- What is the required temporal frequency and resolution (vertical and horizontal) from geostationary microwave data to significantly improve hurricane model performance?

In-flight experience with lightning mapper data demonstrates that it is a useful proxy for intense convection related to ice flux, updraft strength, convective rainfall, diabatic and latent heating. This leads to the question:

- Would a lightning mapper in geostationary orbit provide clues to intensity trends within a tropical cyclone?

Figure 12 Smoke and the hot spots from large wildfires can be observed with the existing GOES imager. For every fire seen at 4 km resolution, there are hundreds of smaller ones burning.

Rapid Development of Wild Fires

The GOES channel 2 IR (3.9 micron) data is very sensitive to sub-pixel size hot spots (Menzel et al., 1994). As a result, large fires (at least 200 acres) and temperatures of 500K can be detected using enhanced 3.9 micron imagery (Purdom, 1996). While AVHRR is better suited for fire detection, it is limited by its polar orbiting time scale.

- Would improvement in geo-stationary IR resolution to 2 km significantly improve its fire detection capabilities?

Satellite imagers and sounders could provide valuable input to numerical models for the atmospheric conditions in the immediate vicinity of large fires.

- What vertical resolution in passive IR and microwave sounders would be required to significantly improve mesoscale model performance?

Explosive Cyclogenesis

Over the past decade, there have been improvements in synoptic scale forecasting of rapidly deepening cyclones out to day 4. However, improvements are needed in defining the mesoscale details of these storms both in the initial analysis and in the subsequent numerical forecasts. Velden (1992), Spencer et al. (1995), and Hirschberg et al. (1997) showed that microwave radiance analyses constructed from polar orbiter data are valuable diagnostic tools that can be used to monitor the progression of important cyclogenesis-related features and processes in the upper troposphere and lower stratosphere, especially when used in conjunction with other satellite-derived products such as ozone measurements. Significantly, these microwave analyses are valid in regions of clouds and precipitation.

- Would a temporal frequency of 1 hour for microwave soundings from geostationary orbit result in improved model performance during periods of explosive cyclogenesis?

Gurka et al. (1995) demonstrated that the GOES imager water vapor data (6.7 microns), when used in conjunction with other data sources such as surface data, upper air data, and numerical model output, can aid in the detection and forecasting of explosive cyclogenesis.

- Would multiple water vapor imager channels with 2 km resolution provide additional benefits for forecasting rapid cyclogenesis over the oceans?

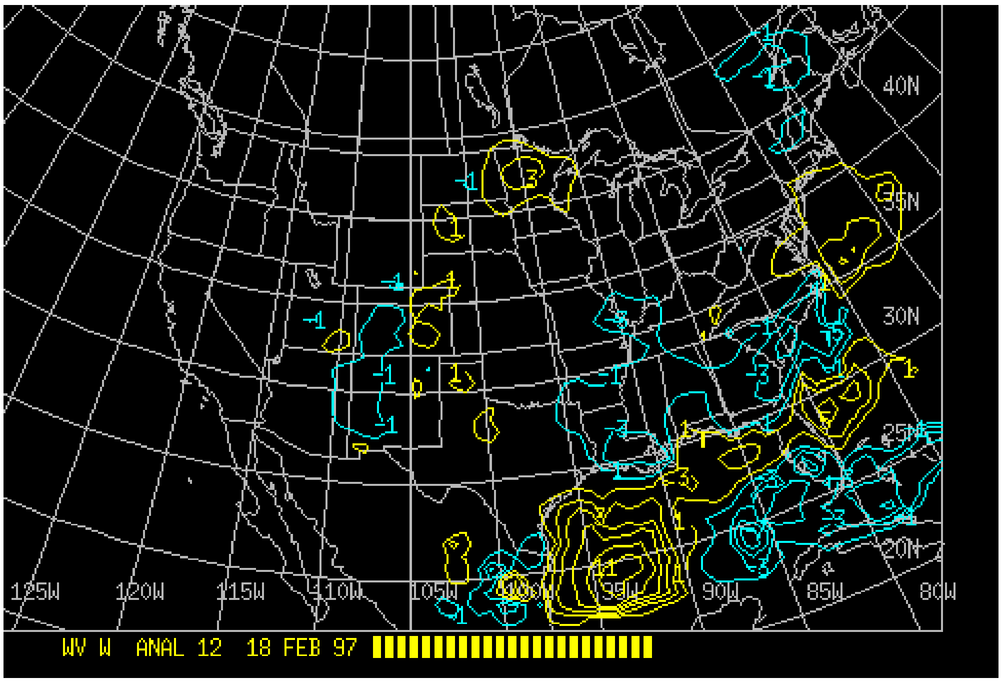

Figure 13 The analysis of GOES satellite sounder data for water vapor over data-void regions such as the Gulf of Mexico provides large corrections to the initial conditions used by numerical weather forecast models. (Aune, et al., 1997)

NWS Needs for the Next Generation GOES Instruments

The last experimental geostationary satellite was ATS-3 in the early 1970s, and the last experimental sensor on a GOES satellite was the VISSR Atmospheric Sounder (VAS) first launched on GOES-4 in 1978. The lack of an experimental satellite as a prototype to the GOES-I through -M series resulted in unnecessary delays cost overruns, and lost opportunities. The answers to the critical questions presented in this section would be provided years earlier with the opportunities provided by a research oriented geostationary satellite. Furthermore, in order to answer the questions posed in the previous sections, it is necessary to utilize a geostationary satellite that is unencumbered by operational constraints. The present GOES-8, for example, has operational commitments to provide 4 imager views over the continental

U.S. per hour and 1 full disk view every 3 hours. These schedule requirements are relaxed only for the operational monitoring of severe weather events at more frequent intervals. Research opportunities from the GOES satellites are severely limited. Furthermore, any instruments flown on the GOES satellites must have proven operational value. Once again, there is very little room for experimentation.

To match expected advances in numerical weather forecasting, the NWS foresees at least a doubling of the space-, time- and spectral-resolution requirements for imaging and sounding from the GOES satellites during the next decade. Indeed, the space-time resolution of current weather models are already beginning to exceed the capabilities of the new GOES-8/9 satellites, designed in the early 1980's. Preliminary studies with the numerical forecast models at the European Center for Medium Range Forecasting (ECMWF) and at the National Center for Environmental Prediction (NCEP) show significant impact by hourly updates of mesoscale water vapor and wind data from geosynchronous satellites. There is also reason for optimism in expecting the current GOES sounding system to contribute to model forecast improvements. Nevertheless, there is also reason to believe that current GOES limitations will inhibit the potential positive impacts over a large number of cases. To address this issue over the next decade, it is anticipated that NOAA’s requirements for vertical temperature sounding accuracy will approach ±1 C in 1 km layers. An advanced sounder must carry both microwave temperature-moisture channels and a very high-resolution infrared radiometer in order to deliver useful data in both cloudy and cloud-free regions. In particular, microwave soundings of the cloudy north Pacific should have a noticeable impact on weather forecasts for the continental USA.

The demands on the future GOES imagers will be just as great. Frequently refreshed, high-quality, full-disk imaging is the NWS highest priority to support the forecast and warning program, especially as they relate to local forecast offices and national service centers.

Meteorological data products from an advanced imager would include:

- Real-time, high resolution imagery in step with the NEXRAD radars.
- Determination of cloud-type, cloud-height, cloud-amount, and cloud-over-snow conditions.
- Dense fields of cloud-tracked and water-vapor tracked winds with mesoscale space-time resolution.
- Water vapor vertical structure in 3 to 4 layers through the troposphere.
- Real time estimates of surface temperature.
- Real time estimates of vertical instability.

An advanced imager could readily deliver performance that is twice as good as the current GOES imager, with radiometry similar to the polar orbiting imagers:

- Full-disk coverage in less than 7 minutes.
- Full-disk-width mesoscale imaging every 30 seconds.

- Simultaneous mesoscale and full-disk imaging at 1 minute and 15 minute intervals, respectively.
- Horizontal resolution from 0.5 km (visible) to 2 km (thermal infrared).
- Earth-location to 1 km uncertainty.
- spectral bands for blue to thermal infrared, including all of the windows and water vapor bands of interest to NWS and MTPE for weather and climate.
- Good calibration in all channels, including the visible and near infrared.
- Signal/noise at least twice as good and many times more stable than the current GOES imager.
- Automated operation, on-demand scanning and real-time data delivery at high rates.

NOAA has identified a need to evaluate the value of real time lightning mapping in the next decade. Fortunately, the Lightning Mapper (LM) developed at NASA-MSFC is an engineering and scientific success now flying in space. A geo-ready version of LM could be developed, and a flight model readied within 2 years of full-funding, to fly in the GOES-N/O era (2001-2005 AD). Most cloud-to-cloud lightning can be observed from space 24 hours per day, providing an indicator of the convective onset of precipitation. This is a valuable indicator of vigorous storm development and energy release in regions outside the NEXRAD radars, such as in the Gulf of Mexico. LM data is easily integrated into real time meteorological analyses with NEXRAD and GOES imagery, and supports emergency warning systems.

Given all of these technical demands to meet the NWS operational forecast requirements being placed on geostationary satellites, an efficient, automated ground system must deliver geosynchronous observations to numerical models and to field forecasters in real-time, in a digital form ready for data fusion with other sources of real-time weather data. A well designed command-and-control advanced geostationary satellite system should be relatively autonomous and as easy to operate.

Finally, NASA and NOAA must justify the cost of expensive space-based systems. The connection between greater resolution and greater knowledge must be estimated by objective simulations. Scientific studies of the impact of a new imager, sounders, lightning mapper and ground system are just as important as the engineering studies that enable these instruments.

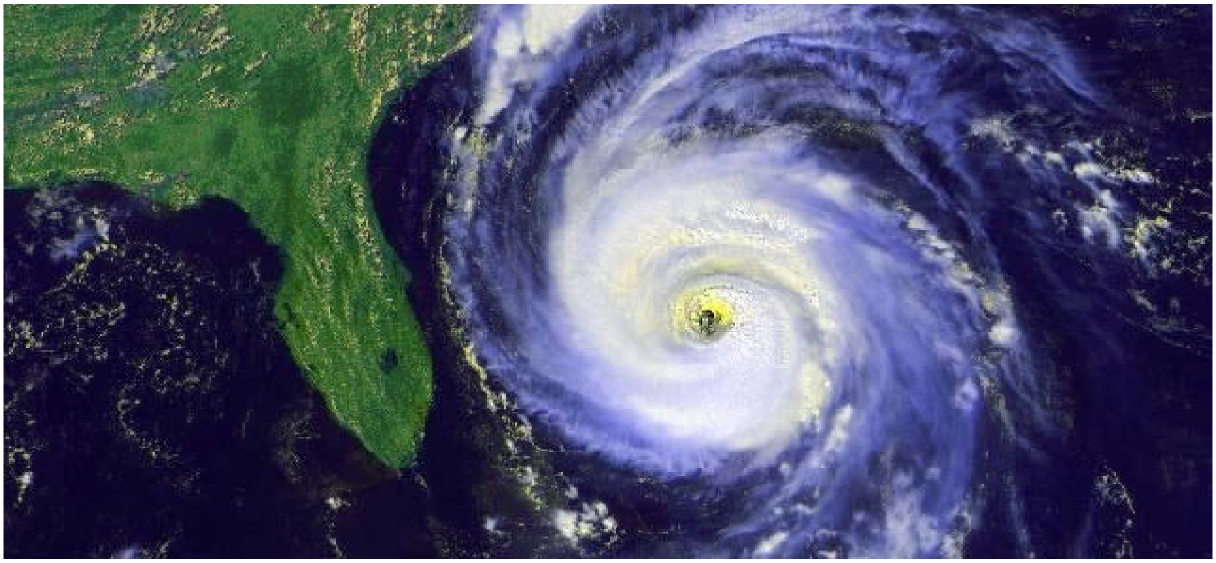

Figure 14 The prediction of hurricane intensity and ground-track are of vital importance to the health and safety of the inhabitants of the southeastern United States. The damage wrought by a single hurricane in a populated area is comparable to comparable to the cost of the entire GOES program over 10 years.

GEO Customers

NOAA operates GOES to make several data products and services. Many of these are delivered to other agencies, and the raw satellite data are publicly available both in real-time broadcasts and in digital archives. The current customers for geosynchronous data who would benefit from improved instrumentation are:

- NOAA National Weather Service (NWS) - nowcasts and forecasts
  - Federal Aviation Administration (FAA) - flight plans and hazards
  - Department of Agriculture - seasonal/regional weather/climate
  - Federal Emergency Management Agency (FEMA) and US Forest Service - hurricanes, floods, lightning, fires, volcanoes, etc.
  - State governments - water supply/resources
  - Search and Rescue (SAR) - international distress signals
- General public - broadcast meteorology, watches and warnings
- NOAA Space Environment Lab (SEL) - space “weather” and solar threats
- NOAA Forecast Systems Lab (FSL) - infusion of new information
- Department of Defense (DoD), USAF, Navy, Coast Guard - weather and sea surface
- European Center for Medium-range Weather Forecasting (ECMWF) - atmospheric analysis and weather forecasting
- NSF National Center for Atmospheric Research (NCAR) - cloud processes
- NASA Mission to Planet Earth - accurate diurnal behavior
- US Global Change Research Program (USGCRP) - long-term climate analysis and forecasts

NOAA is the official archive agency of climate records in the United States. As a member of the USGCRP, NOAA's climate analysis and forecast office will be its own best customer of a long, uniform series of high quality geosynchronous observations.

GEO SYNERGY WITH LEO

Parameters Observed from LEO and GEO

The 1996 ES science research plan targeted twenty-four environmental variables for systematic observation from low earth orbit (LEO). The following table lists those variables that are reasonably observable from LEO and from advanced geosynchronous earth orbit (GEO) remote sensors. The table gives more marks to the better determined variables expected from the EOS-funded LEO instruments and from potential advanced GEO instruments. <u>The justification for these marks is debatable, of course, and must be addressed by systematic advanced geosynchronous studies.</u>

ENVIRONMENTAL VARIABLES (•••=best)	**EOS LEO**	**Adv. GEO**
Atmosphere		
cloud properties	••	••
radiative energy fluxes	•••	•
precipitation	•••	••
tropospheric chemistry	•••	••
stratospheric chemistry	•••	••
aerosol properties	••	•
atmospheric temperature	•••	••
atmospheric humidity	•••	•••
lightning	••	•••
Land		
land cover & land use	•••	•
vegetation dynamics	•••	••
surface temperature	••	••
fire occurrence	••	••
volcanic effects	••	••
surface wetness	••	•
Ocean		
surface temperature	•••	••
phytoplankton & dissolved organic matter	••	•
surface wind fields	•••	
ocean surface topography	•••	
Cryosphere		
ice sheet topography & ice volume change	•••	
sea ice	•••	
Solar Radiation		
total solar irradiance	•••	•••
ultraviolet spectral irradiance	•••	••

Rows in the above table where GEO is within one mark of LEO are strong candidates for geosynchronous instrumentation, especially where the parameter has chaotic behavior and a strong diurnal cycle. In particular, GEO observations are an excellent source of information about rapidly changing clouds, winds and water vapor. The table also gives marks where new GEO instrumentation is feasible, but not yet listed on the AGS priority list for advanced observations.

Figure 15 The global coverage provided by LEO instruments necessarily has spatial gaps and a low rate of re-visit that is complemented by continuous observations from GEO.

Synergy between LEO and GEO Regional Studies

There are two high priority regions identified for ES case studies:

- US and the Americas
- Amazon

These regions are the standard operational targets for GOES. The vast and rapidly changing fires and aerosols, lightning, clouds and rainfall in the Amazon are particularly well observed at nadir from GOES-EAST at 75W, while meagerly sampled by the EOS polar orbiters.

Synergy between LEO and GEO Instruments

The specific synergy between each of the proposed advanced geo-instruments with corresponding EOS and NPOESS instruments are:

- A prototype advanced geo-imager with spectral bands like MODIS in the EOS-PM era would demonstrate the value-added for time-resolved observations of atmospheric processes like aerosols and clouds during the diurnal cycle. It would also provide cloud- and moisture-tracked motions with unprecedented space-time density in the western hemisphere.
- A prototype high resolution infrared geo-sounder during the PM-1 and NPOESS overflights would demonstrate the ability to capture the 4-dimensional behavior of temperature, moisture, clouds, and rare gas constituents between daily overpasses by the polar orbiters.
- A prototype high frequency microwave geo-sounder during the AMSU and advanced IR sounder overflights would demonstrate the value of flying these state-of-the-art frequencies in space, and evaluate their sensitivity to vertical moisture and temperature variations.
- A prototype high frequency microwave geo-imager during the SSM/I, TRMM, AMSR and NPOESS microwave imaging overflights would demonstrate the value of observing these frequencies continuously, and evaluate their sensitivity to precipitation.
- A prototype geo-lightning mapper flown during the LIS and TRMM follow-on mission would provide time-continuous observations over the western hemisphere between the sparse observations by the polar orbiter, with the polar orbiter providing validation.
- A new ground system would include a very high capacity data downlink, storage and distribution system using the file formats, data-indexing and data-retrieval methods adopted by ES/EOS and NPOESS, making it possible to use all remotely sensed data sources for earth system science.

Unique Information from GEO

Some specific information benefits from an advanced geosynchronous system are:

- Radiometric cross-reference between EOS satellites in different orbits, and gap-fillers for EOS platforms launched with time-gaps.
- Diurnal cycle and changing time-of-day characteristics of cloudtop amount, height and phase.
- Tropospheric moisture -- humidity, transport and turbulence, radiation loss.
- Dense fields of cloud-tracked and water-vapor tracked winds at hourly intervals, especially in the tropics.
- Daytime aerosol monitoring with 15-minute resolution.
- Observation of short-lived and unpredictable events like volcanic eruptions, fires, and red tides.
- IR cloudtop temperature as a surrogate for precipitation.
- Lightning mapper activity for NO2 production and as a surrogate for precipitation.
- Time-composite cloud-free views of surface conditions such as vegetation and surface temperature.
- Bi-directional spectral reflectance of vegetation, clouds, and aerosols for varying sun-angles from a fixed viewing angle.
- Consistent operational coverage and digital archives for 10 to 20 years.
- Accurate and complete statistics of events in a hemisphere.

Utilization of GEO and LEO Data by NWS

In the past, data from low earth-orbiters (LEO) have been used primarily for longer range prediction and climate issues, whereas data from geostationary satellites have been used in NWS forecast offices for issuing short term forecasts and warnings. Furthermore, while LEO data has been used primarily in a quantitative mode for input into numerical models, geostationary satellite data has been used primarily in a qualitative image mode by forecasters dealing with hazardous weather events such as tornadic storms and hurricanes.

This situation has begun to change due to a number of factors, including: 1) the launch of GOES-8 in April, 1994, carrying an advanced, operational 19 channel sounder; 2) continued improvements of LEOs planned for launch in the near future; and 3) general advancements in weather and climate forecasting. Requirements are now evolving that dictate the use of GOES data in a quantitative mode at national modeling centers for use in numerical prediction systems and at local forecast offices for producing derived product images (e.g. stability indices, total precipitable water, and the low cloud product). Furthermore, the utilization of LEO data is being extended beyond the national centers for use in local and regional forecast offices for the computation of specialized products (e.g. soil moisture and precipitable water from SSMI; winds from NSCAT etc.). It is becoming readily apparent that both GOES and LEO data sets will have to be applied as a “mix” of observations that can address both weather analyses and forecasts produced throughout the National Weather Service, including the national centers and the local forecast offices.

Digital satellite data is now more easily accessible through the infrastructure that supports the NWS field structure. For example, NCEP ingests the following data into their numerical models: 1) the vertical and horizontal distribution of water vapor from LEO sounders; and 2) clear air radiances from LEO sounders. By the end of 1997, the following digital satellite data will also be input into NCEP's models: 1) 3-layer precipitable water from GOES sounders; 2) clear air radiances from GOES sounders; and 3) high density water vapor and cloud-track winds from GOES imagers. Digital satellite products available at the NWS forecast offices include: the low-cloud product, derived from the GOES imager and the lifted index and precipitable water, derived from both the GOES imager and sounder. Furthermore, the local forecast offices have access to quantitative precipitation estimates derived from GOES imager data, GOES sounder data (total precipitable water), and LEO sounder data (precipitable water from microwave sounders); and quantitative estimates of snowfall rates from lake effect snow (LES) bands, based on GOES imager data. The distinction in the use of LEO and GEO data by national centers and field forecast offices is now being blurred by the ready access to the digital data sets produced by both satellite systems.

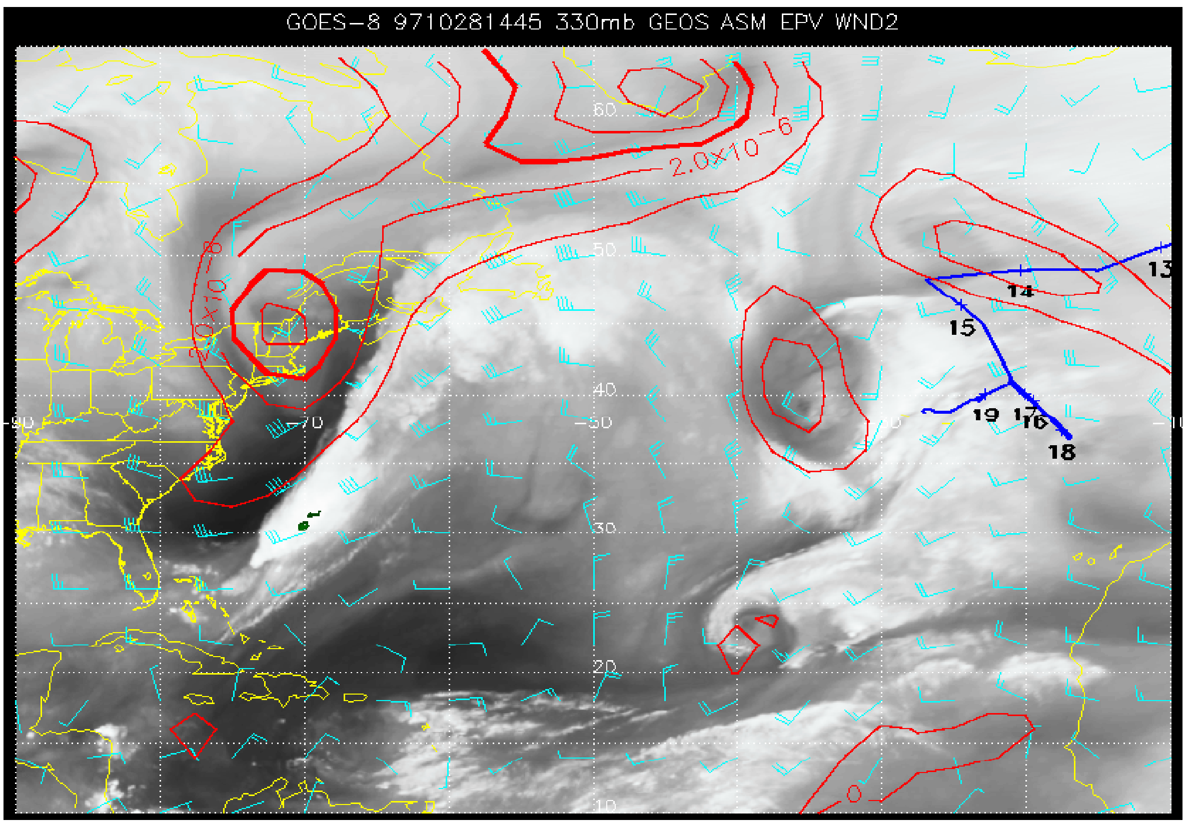

Figure 16 Winds in the upper troposphere can be derived at hourly intervals using motion in the 6.7 micron water vapor band as a tracer. In this case, the vapor-tracked winds are combined with a potential vorticity analysis in support of an experimental flight designed to analyze the movement of intercontinental aircraft exhaust in the upper air. (Velden et al., 1997)

THE ADVANCED GEOSYNCHRONOUS STUDIES (AGS) PROGRAM

In 1997, the Earth Science Program Office requested Goddard Space Flight Center (GSFC) to initiate Advanced Geosynchronous Studies (AGS) for the benefit of both the research and operational communities. A joint NASA-NOAA group was formed to guide these studies.

The purpose of AGS is to foster advanced geosynchronous instruments and missions in order to:

- Meet the observational requirements of NOAA's operational program.
- Provide the observations required to answer high priority science questions from the research community.

An Advanced Geosynchronous Studies (AGS) Science Workshop was held in College Park, MD March 23-25, 1998 to establish high priority science questions in four research areas: Climate Processes, Atmospheric Chemistry, Atmospheric Dynamics, and Surface (Land and Ocean) Processes. These questions have led to a set of geophysical observational guidelines that serve as a first step in determining observational and instrument requirements for research/operational missions to address the science questions.

Currently five instrument/technology areas being emphasized in AGS are:

- Fast multi-spectral imager, with 0.5 km (shortwave) to 2 km (longwave) resolution in all the atmospheric windows, with signal/noise>500/1, and 4 or more full-disk images per hour.
- High resolution infrared sounder, with hourly full-disk scans at 10 km resolution and spectral resolution>2000/1.
- Microwave sounder, with hourly coverage at 20 km or better resolution in temperature and moisture lines.
- Lightning mapper, with minute-by-minute coverage at 10 km resolution.
- Automated ground system, with standard databases and realtime distribution.

The accompanying table relates the four main instrument areas being studied in AGS to the science questions in section 2. All the instruments make significant contributions with varying emphases. These estimated relative contributions are approximate, but are meant to convey how the instruments are related through their observables back to the original science questions driving the program. The list of instruments could also be longer, including possible ocean color, volcanic hazards, chemistry or other specialized instruments.

One current focus of AGS is the development of a joint NASA/NOAA mission concept that would combine observations to answer high priority questions for the research community and meet NOAA's requirement for development of its next generation geosynchronous imager and sounder and other possible small instruments.

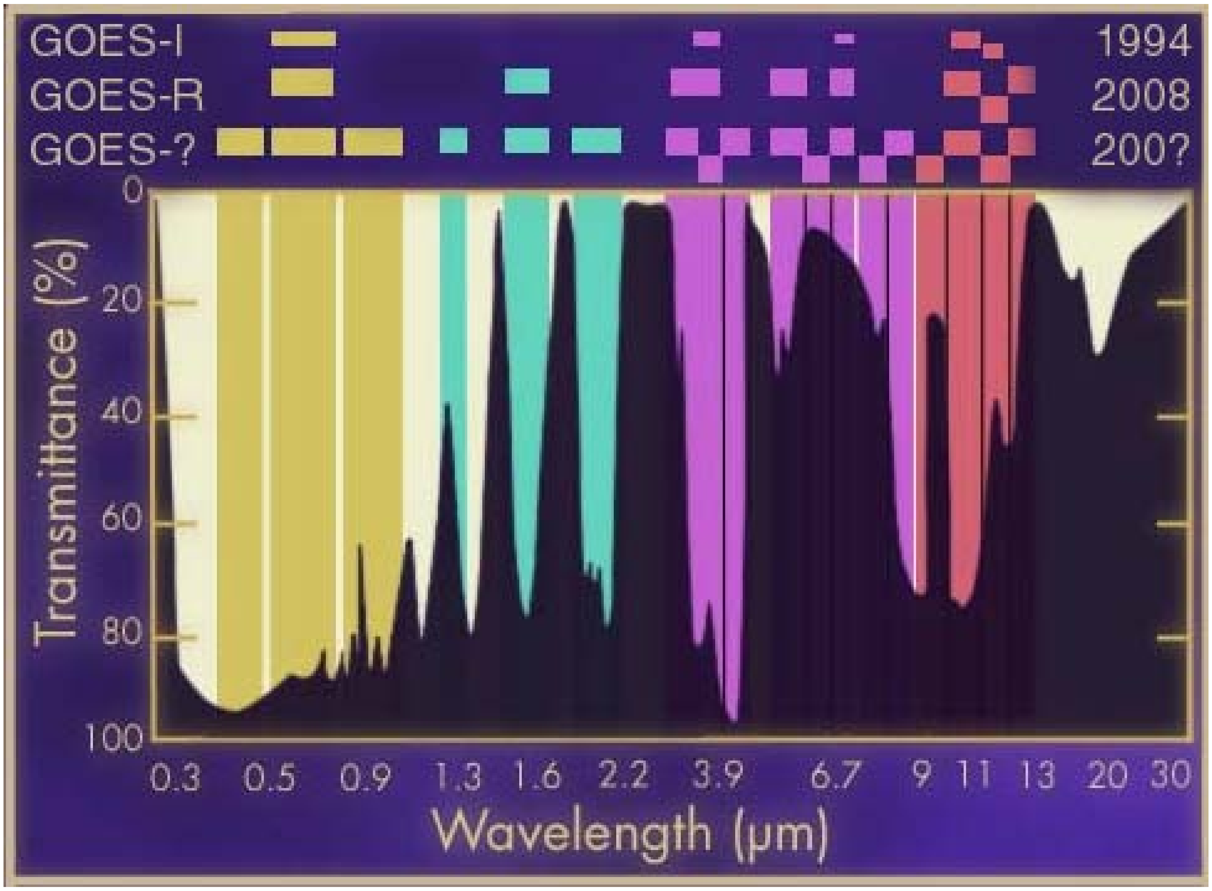

Figure 17 The next generation geosynchronous imager could observe in all the atmospheric windows and water vapor absorption bands useful for earth science, and complement the corresponding imaging instruments in LEO. (Chesters et al., 1996)

For example, the role of the GOES Imager could be expanded to observe the entire spectrum from visible to thermal infrared at moderate spectral resolution and high spatial resolution, meeting both the current (GOES-I) and future (GOES-R) requirements along with the EOS MODIS requirements.

Likewise, the GOES infrared Sounder could be improved to resolve the three-dimensional mesoscale distribution of water vapor in the lower troposphere, as has already been demonstrated in aircraft experiments.

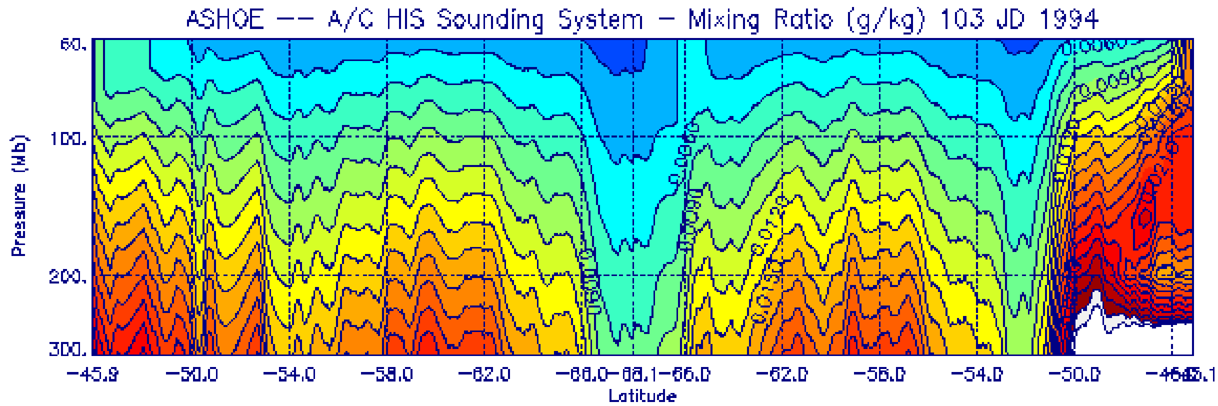

Figure 18 An infrared interferometric sounder was used to produce this high-resolution vertical cross section of water vapor during aircraft experiments near Australia. (Smith et al., 1994)

Cross-reference between AGS science questions and the four main AGS instruments

The number of marks in the table below indicate the degree to which the instruments will contribute to progress (new or better information than currently available) in answering the science questions.

AGS Science Questions • = helpful, •• = very useful, ••• = prime	Imager	IR Sound er	Microwave Sounder	Lightning Mapper
Climate Processes				
Aerosols	•••			
Clouds and Radiative Forcing	•••	•••	••	
Water Vapor Cycle	•••	•••	•••	
Precipitation	•	•	••	••
Atmospheric Chemistry				
Convective Transport	•	••	•	•
Circulation	•	••	•	
Regional Climatology	•	••	•	•
Atmospheric Dynamics				
Convective Systems	•••	•••	••	••
Tropical Cyclones	••	••	•••	•
Extratropical Cyclones	••	•••	•••	
Surface Processes				
Coastal Mixed Layer	••			
Variability of SST and Currents	••	••		
Land Surface Fluxes	••	•		
Surface Hydrology	••	•	••	••

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Acknowledgments

This document was composed primarily by Dennis Chesters and Bob Adler with suggestions and corrections from (in alphabetical order): Scott Braun, Russ Dickerson, Franco Einaudi, Jim Gurka, Gary Jedlovec, Del Jenstom, Yoram Kaufman, Dan Keyser, Chris Kummerow, Arthur Hou, Greg Mandt, Dave Martin, Paul Menzel, Marshall Shepherd, Eric Smith, and Louis Uccellini.